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STS 65 Final Report

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1.0 INTRODUCTION

The report is organized into sections representing the phases of work performed in analyzing the STS 65 results and preparing the instrument for STS 73. Section 1 briefly outlines the OARE system features, coordinates, and measurement parameters. Section 2 describes the results from STS 65. The mission description, data calibration, and representative data obtained on STS 65 are presented. Also, the anomalous performance of OARE on STS 65 is discussed. Finally Section 3 presents a discussion of accuracy achieved and achievable with OARE.

1.1 OARE System Features

The Orbital Acceleration Research Experiment (OARE) contains a tri-axial accelerometer which uses a single free-floating (non-pendulous) electrostatically suspended cylindrical proofmass. The accelerometer sensor assembly is mounted to a microprocessor-controlled, dual-gimbal platform in order to perform in-flight calibrations. Acceleration measurements are processed and stored in the OARE flight computer memory and, simultaneously, the unprocessed data are recorded on the shuttle payload tape recorder. The payload tape recorder data are telemetered periodically to ground stations during flight via tape recorder playback (data dumps).

OARE's objectives are to measure quasi-steady accelerations, to make high resolution low-frequency acceleration measurements in support of the micro-gravity community, and to measure Orbiter aerodynamic performance on orbit and during reentry. There are several features which make the OARE desirable for making highly accurate, low-frequency acceleration measurements. OARE is the first high resolution, high accuracy accelerometer flight design which has the capability to perform both bias and scale factor calibrations in orbit. Another design feature is the OARE sensor electrostatic suspension which has much less bias temperature sensitivity than pendulous accelerometers. Given the nature of the OARE sensor and its in-flight calibration capability, OARE stands alone in its ability to characterize the low-frequency environment of the Orbiter with less than 10 nano-g resolution and comparable accuracy.

1.2 Coordinate Systems

Two coordinate systems are used in this report -- the OARE axes centered at the OARE sensor proofmass centroid and the Orbiter aircraft body axes centered at the Orbiter's center of gravity. The direction from tail to nose of the orbiter is +X in both systems. The direction from port wing to starboard wing is +Z in the OARE system and +Y in the Orbiter system. The direction from the Orbiter belly to the top of the Orbiter fuselage is +Y in the OARE system and -Z in the Orbiter system. This sensor-to-body coordinate alignment is referred to as the nominal flight alignment and was utilized for OARE data collection during STS 65.

In discussions of OARE calibrations of bias and scale factor, the OARE reference system is used. Flight acceleration data are given in the Orbiter body reference system. The sign convention is such that when there is a forward acceleration of the Orbiter (such as the OMS firing), then this is reported as a positive X axis acceleration. All accelerations given in this report refer to the OARE location.

1.3 Sensor Measurement Parameters

There are three sensor ranges A, B, and C for each OARE axis, which are controlled by auto-ranging software logic. The full scale ranges and resolutions (corresponding to one count) are given in Table 1. In any case where the sensor channel is driven into saturation, the output is set to 1.5 times full scale of range A with the sign of the saturation signal included.

Table 1. OARE Sensor Ranges and Resolutions

Range	Full Scale Range in micro-gs	
	X-Axis	Y & Z Axes
A	10,000	25,000
B	1,000	1,970
C	100	150
Range	Resolution in nano-gs	
	X-Axis	Y & Z Axes
A	305	763
B	30.5	58.0
C	3.05	4.6

2.0 STS 65 MISSION RESULTS

This section describes the results from STS 65 as derived from post-flight analyses of the on-board stored EPROM processed data and from the telemetered unprocessed data.

2.1 STS 65 Mission Plan

The STS 65 adaptation parameters anticipated a mission of up to 14 days long. The calibration plan was to perform bias calibrations at 251 minute intervals and to perform scale factor calibrations in conjunction with every third bias calibration. The STS 65 plan did not include any predefined "Quiet" periods in that "around the clock" astronaut operations were planned.

2.2 STS 65 Actual Mission Description

Launch for STS 65 was on 8 July 1994. The actual length of the OARE STS 65 mission was 14 days, 17 hours, 56 minutes, and 9 seconds. Shutdown occurred in REENTER mode under the condition of "re-capture duration error" in sub-mode 4. This means that the OARE instrument continued to collect data until the Y axis signal was saturated for at least 2 minutes in the final REENTER sub-mode. This is considered normal termination of the mission, and represents adequate adaptation parameter settings for the reenter file size and correct timing of the reenter discrete.

The OARE was turned on once, 3:50 (hh:mm) prior to launch. Quiet was asserted "ON" during day # 13 (the first day of the mission is day # 0) for 2 closely spaced periods of about 3 hrs. each. Reenter was asserted then canceled twice during day #13 then asserted for actual reentry on day #14. The system remained in Reentry for 71:18 (mm:ss) before a normal shutdown due to sensor

saturation. The E²PROM flight data were recovered by accessing the OARE SPCS on Orbiter OV-102 via the GSE on 5 August 1994.

All engineering parameter values were within normal range. Hardware performance was normal.

2.3 STS 65 Data Analysis

This section treats the several analyses carried out on the STS-65 flight data and summarizes the significant results. The processed acceleration data and the EPROM files have already been delivered to Microgravity Measurements and Analysis Branch at NASA Lewis Research Center.

The Orbital Acceleration Research Experiment (OARE) is designed to measure quasi-steady accelerations from below 10 nano-g up to 25 milli-g where quasi-steady indicates the frequency range from DC to 1 Hz. To accomplish this, the sensor output acceleration signal is filtered with a Bessel filter with a cut-off frequency of 1 Hz. The output signal is digitized at 10 samples per second and is then further processed and digitally filtered onboard the OARE instrument with an adaptive trimmean filter prior to EPROM storage.

In flight, the OARE instrument is subjected to higher amplitude and higher frequency accelerations (such as structural and crew noise effects) in addition to the quasi-steady accelerations such as those due to gravity gradient and on-orbit drag. However, these higher accelerations are not well characterized nor statistically invariant over the OARE measurement periods. Because of limited OARE flight memory, the sampled data of 10 samples per second is further processed to estimate the quasi-steady acceleration over sample periods of 50 seconds.

In order to obtain the optimum estimate of the quasi-steady acceleration under these conditions, a robust adaptive estimator has been implemented. For a discussion of robust estimators see Reference 1. The particular estimator used is known as the Hogg Adaptive Trimmean estimator and is described in Reference 2. In essence, the adaptive trimmean estimator examines the distribution of the measurement points over a given period (typically 50 seconds on STS 65) and determines the size of the tails of the distribution (or its departure from a normal distribution). Based upon its measurement of the size of the tails of the distribution, it adaptively chooses the size of the trim to be used for estimating the mean of the underlying population. The larger the percentage of the distribution in the tails, the larger the trim that is used in estimating the mean. For OARE on-orbit processing, the trimming ranges from 10% to 80% of the total distribution as discussed in Reference 2.

The data analyzed and presented in this report is primarily that which was recorded on-board and has been processed by the on-board trimmean filter in 50 second periods. The telemetry data at 10 samples per second which has not been processed by the trimmean filter as well as the acceleration data presented in this report are available from the Microgravity Measurements and Analysis Branch at NASA Lewis Research Center.

The temperature environment was cold for most of the STS 65 mission but was relatively constant from mission elapsed time (MET) of 50 hours through MET of 300 hours. The instrument temperature in degrees Celsius (measured on the proofmass housing) is shown in Figure 1.

STS 65 INSTRUMENT TEMPERATURE

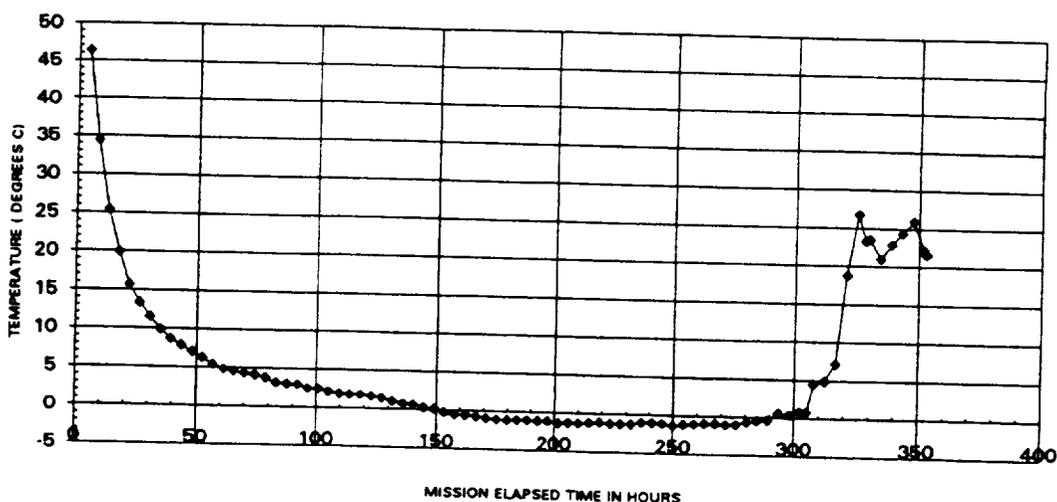


Figure 1. STS 65 Instrument Temperature Measured During X-Axis Bias Calibrations

2.3.1 Bias Data Analysis

One determinate of the overall accuracy of the acceleration measurement data is the accuracy of the bias determination of the OARE instrument as a function of time during the mission. On STS 65, bias calibrations were made 5.7 times a day.

In the process of measuring the bias for each sensor axis, the OARE sensor is held in its standard position and 50 seconds of data are collected at 10 samples per second. These data are then processed through the trimmean filter which calculates a "best" estimate of the DC signal by removing the outlying data points which may be caused by various higher frequency activity such as crew activity, thruster, evaporators, pumps, vibrations, etc.; then the mean and the average deviation of the remaining measurements from the 500 initial samples are calculated. The sensor is then rotated 180 degrees and a new set of measurements is made and processed by the trimmean filter. The outputs are then summed and divided by two to obtain the measured estimate of the true bias in counts for that bias calibration event.

In order to obtain the most accurate measurement of the instrument bias, there should be no noise or offset contributions to the measurement of the means except the intrinsic instrument noise and DC accelerations. However, the shuttle activity's contribution to the noise exceeds the intrinsic noise of the instrument and any changes in the average acceleration between the two bias measurements will contribute to an error in the measured bias. Thus, there may be a significant measurement error on each bias measurement. These measurement errors inherently limit the accuracy obtainable from the bias calibration process.

The bias can be characterized by an initial transient after launch as a function of time and a small dependence upon temperature. In the same manner as on STS 62 [3], we have fitted the measured bias data with a function of the following form:

$$\text{Bias} = A_1 + A_2 * e^{-(t/t_0)} + A_3 * e^{-(t/t_1)} + A_4 * T,$$

where A_1, A_2, A_3, A_4, t_0 and t_1 are fitted coefficients, t is the mission elapsed time in hours, and T is the instrument temperature in degrees Celsius.

The true bias in counts was estimated by performing a least squares fit to the trimmean bias measurements. The functional form of the fit was the two exponential form with a linear temperature term as given above. The results of these fits are shown in Figure 2 for the OARE X, Y, and Z axes on the C-Range. The measured and fitted bias are shown and are to be read along the left axis. The residual errors between the fitted bias and the measured bias are also shown and can be read along the right axis. The conversion from counts to nano-gs is given as resolution in Table 1. The fitted coefficients and corresponding metrics of the fits are shown in Table 2.

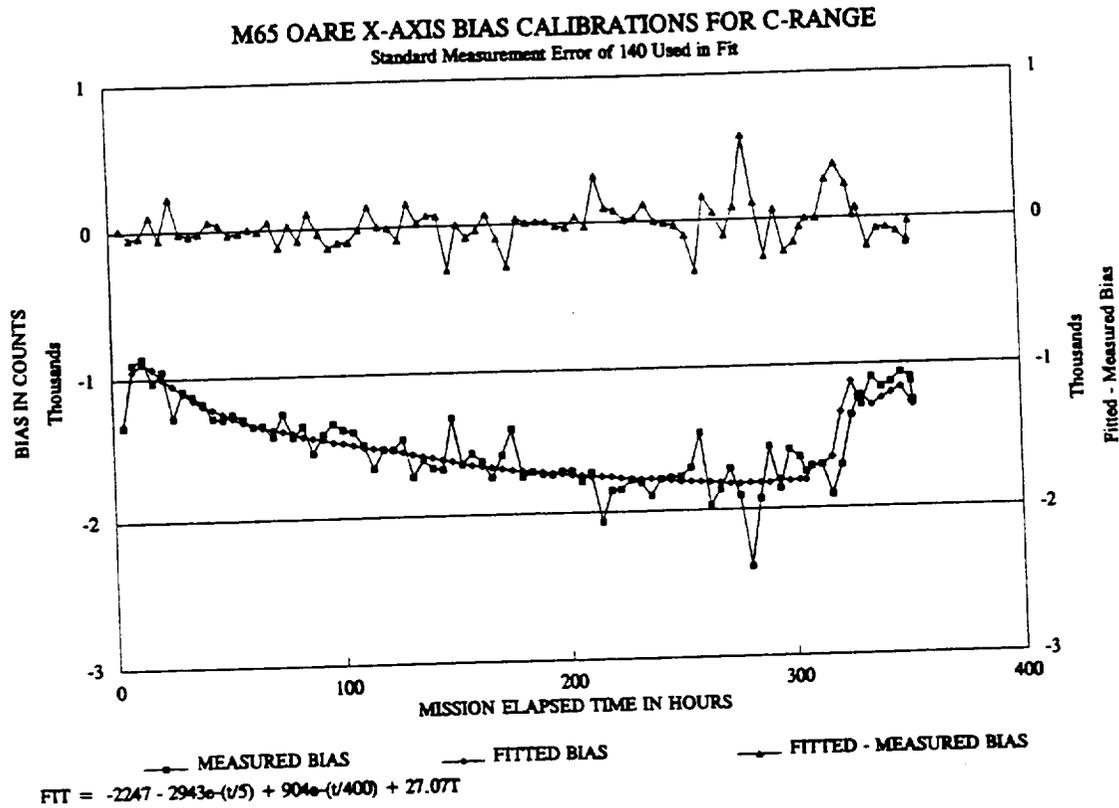


Figure 2a. OARE Bias Measurements and Estimated Biases for the X axis in C Range

M65 OARE Y-AXIS BIAS CALIBRATIONS FOR C-RANGE

Standard Measurement Error of 30 Used in Fit; Outlier points removed

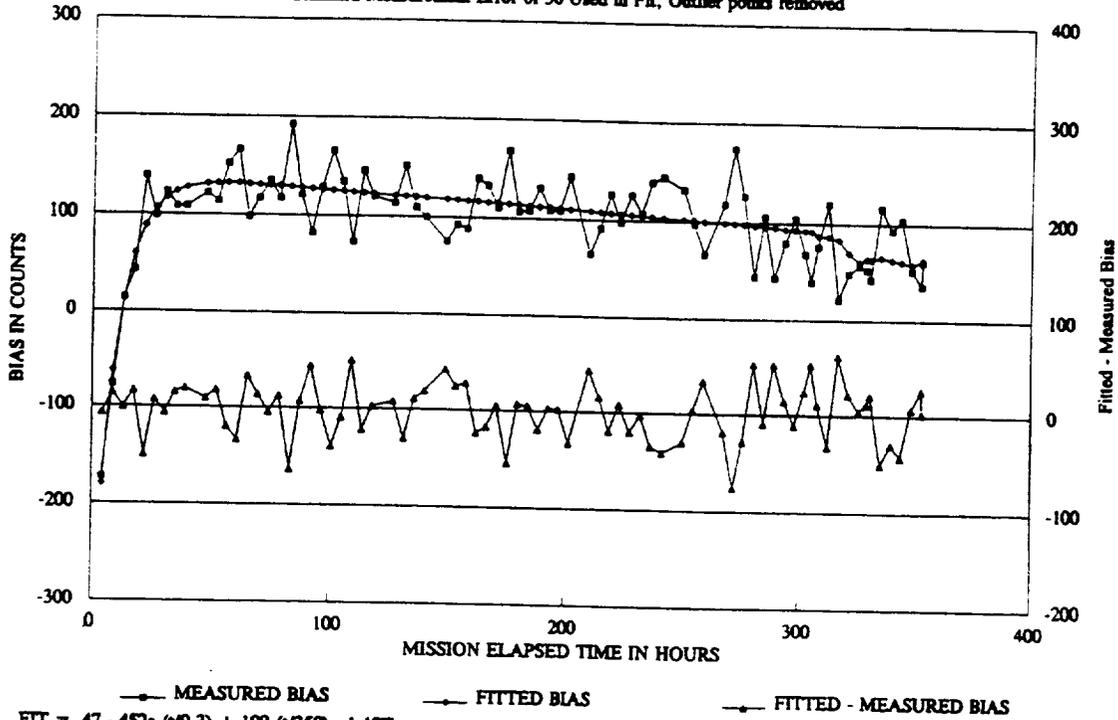


Figure 2b. OARE Bias Measurements and Estimated Biases for the Y axis in the C Range

M65 OARE Z-AXIS BIAS CALIBRATIONS FOR C-RANGE

Standard Measurement Error of 22 Used in Fit—Outlier Point Removed

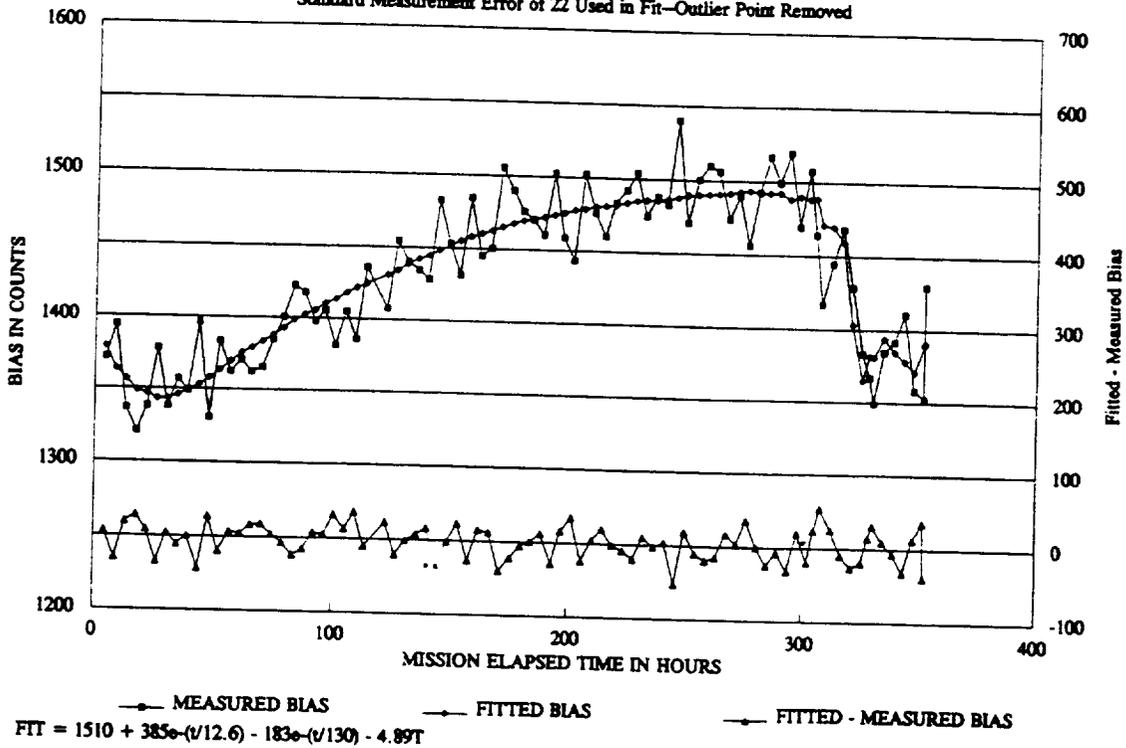


Figure 2c. OARE Bias Measurements and Estimated Biases for the Z Axis in C Range

The functional fit captures the trend of the bias measurements with no major deviations over long periods of time, as shown in Figure 2; this would indicate that the functional form of the fit is generally adequate. The differences between the fit or estimate of the true bias and the measured bias are believed to be largely due to the inherent uncertainty in the measurement of the bias as a result of the large noise generated as a result of crew activity and other exogenous events aboard the shuttle. During quiet periods such as those on STS 62, the differences are generally much less than those shown here.

Table 2. STS 65 Bias Fit Analysis (See Note Below)

OARE X-AXIS			
	C	B	A
RANGE	-2247.4*	-231.5	5.33
FITTED CONSTANT A1	-2942.6	-209.1	4.82
FITTED CONSTANT A2	904.0	100.4	6.95
FITTED CONSTANT A3	27.07	2.92	0.266
FITTED CONSTANT A4	5	5.75	5
FITTED CONSTANT θ	400	500	400
FITTED CONSTANT θ			
STANDARD DEVIATION OF FITTED-MEASURED	138.4	11.0	1.25
R-SQUARED OF FIT	0.777	0.861	0.865
OARE Y-AXIS			
	C	B	A
RANGE	47.3*	25.23	28.67
FITTED CONSTANT A1	-451.6	-47.0	-98.26
FITTED CONSTANT A2	108.8	5.08	-6.54
FITTED CONSTANT A3	-1.12	-0.732	-0.751
FITTED CONSTANT A4	9.3	6.8	1.5
FITTED CONSTANT θ	350	75	9.5
FITTED CONSTANT θ			
STANDARD DEVIATION OF FITTED-MEASURED	29.0	3.3	0.59
R-SQUARED OF FIT	0.992	0.879	0.995
OARE Z-AXIS			
	C	B	A
RANGE	1510.3*	232.78	173.62
FITTED CONSTANT A1	385.1	30.08	20.58
FITTED CONSTANT A2	-183.3	-15.86	-8.55
FITTED CONSTANT A3	-4.89	-0.369	0.039
FITTED CONSTANT A4	12.6	11.8	10.4
FITTED CONSTANT θ	130	220	46.8
FITTED CONSTANT θ			
STANDARD DEVIATION OF FITTED-MEASURED	22.0	2.7	0.88
R-SQUARED OF FIT	0.843	0.664	0.705

*Note: For processing raw telemetry data, the fitted constants A1 on the C range for the OARE X, Y, and Z axes are -2241.7, 48.9, and 1511.8, respectively. See section 2.3 for discussion.

In the above analysis of bias, a visual examination of the 10 sample per second data time plots for the bias measurements indicated that there was a large negative transient signal included in the YZ opposite position bias signal measurements as a result of completing the table movement and not allowing sufficient Y axis electronic settling times on the C-range bias calibration. Further analysis indicated that this induced transient's effect on the bias estimate was not completely removed by the trimmean filter. In fact, it skewed the bias by 50 ± 4 counts for the Y estimate and 6.5 ± 1.5 counts for the Z estimate in the C-range. These corrections have been incorporated into the bias measurements shown in Figure 2 and Table 2. The amount of skewing is dependent upon the noise level. For missions such as STS62, where there are quiet periods, the bias measurement offsets would be less.

2.3.2 Scale Factor Data Analysis

Scale factor measurements are made by passing a known, non zero, signal through the sensor and electronics for each channel and each range. These measurements may be contaminated by noise in the external environment or by internal noise in several forms.

For OARE, the method of scale factor calibration involves rotating the Motor/Table Subsystem (MTS) (sometimes called "the table") at a known angular rate ω with a fixed sensor to center-of-rotation offset radius r . The known signal is thus the controlled centripetal acceleration. While collecting scale factor data, the sensor also experiences a bias (assumed fixed) and is exposed to an external signal. Data collected before and after the scale factor slew assists in removing the bias and external signal effect.

The basic scale factor measurement model is shown in Figure 3.

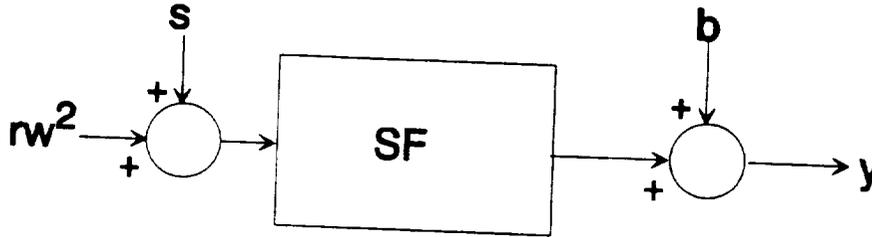


Figure 3: Scale Factor Measurement Model

From this model, the k^{th} measurement y_k is given by:

$$y_k = (r\omega^2 + s_k) / SF_A + b_k$$

where s_k is the signal at the k^{th} measurement time and b_k is the internal bias at the k^{th} measurement time. We assume that ω is constant throughout the slew. We will also assume that s_k contains two components: (i) an acceleration signal which is fixed with respect to the MTS base throughout the slew and (ii) a noise input with zero mean. To eliminate noise, consider averages of the measurements over the data set (with length n):

$$\bar{y} = (r\omega^2 + \frac{1}{n} \sum_{k=1}^n s_k) / SF_A + \bar{b}$$

where $(\bar{\quad})$ is the average value of (\quad) .

From this equation we can find the actual scale factor SF_A . Here, y is the average of the measurements and $r\omega^2$ is known. The remaining unknown, s_k , is a combination of the external signal and noise. This is related to the midpoint measurement. During the slew, the sensor records varying magnitudes of the external signal. The bias and centripetal acceleration, however, remain fixed in magnitude. If the measurements are centered around the midpoint, the midpoint measurement can be used to estimate this external signal and remove it from the scale factor equation. It can be shown that the influence that the external signal and bias have on the scale factor measurements is related to the sinc function $(\sin(x)/x)$ of the angular travel. The actual scale factor can then be found from the following equations:

$$1/SF_A = \frac{\bar{y} - MP(\sin(\delta)/\delta) - (1 - (\sin(\delta)/\delta))\bar{b}}{r\omega^2}$$

The scale factor correction is $SF_C = SF_A / SF_N$, where SF_N is the nominal scale factor.

Scale factor corrections were calculated for all three OARE axes and the three ranges. The results are shown in Table 3.

Table 3. Scale Factor Correction Factors for M65 OARE Axes and Ranges

AXIS	RANGE	VALUE
X	A	1.072
X	B	1.06
X	C	1.025
Y	A	1.158
Y	B	1.164
Y	C	1.172
Z	A	1.113
Z	B	1.128
Z	C	1.131*

*This Scale Factor Correction was computed from the B range measurement.

2.3.3 Orbiter Body Axis Accelerations Results

The accelerations measured by OARE at the OARE location in the Shuttle Body Axes coordinate system (X- toward nose, Y-toward the starboard wing, Z-down through the belly) are shown in Figures 4-10 for representative time periods. Figures 4, 5, and 6 show the acceleration during the entire mission. Figure 7 shows the induced acceleration at the OARE location during Orbiter maneuvers. Figures 8-10 show a period of a nominal noise level followed by a more quiet period near the end of the mission.

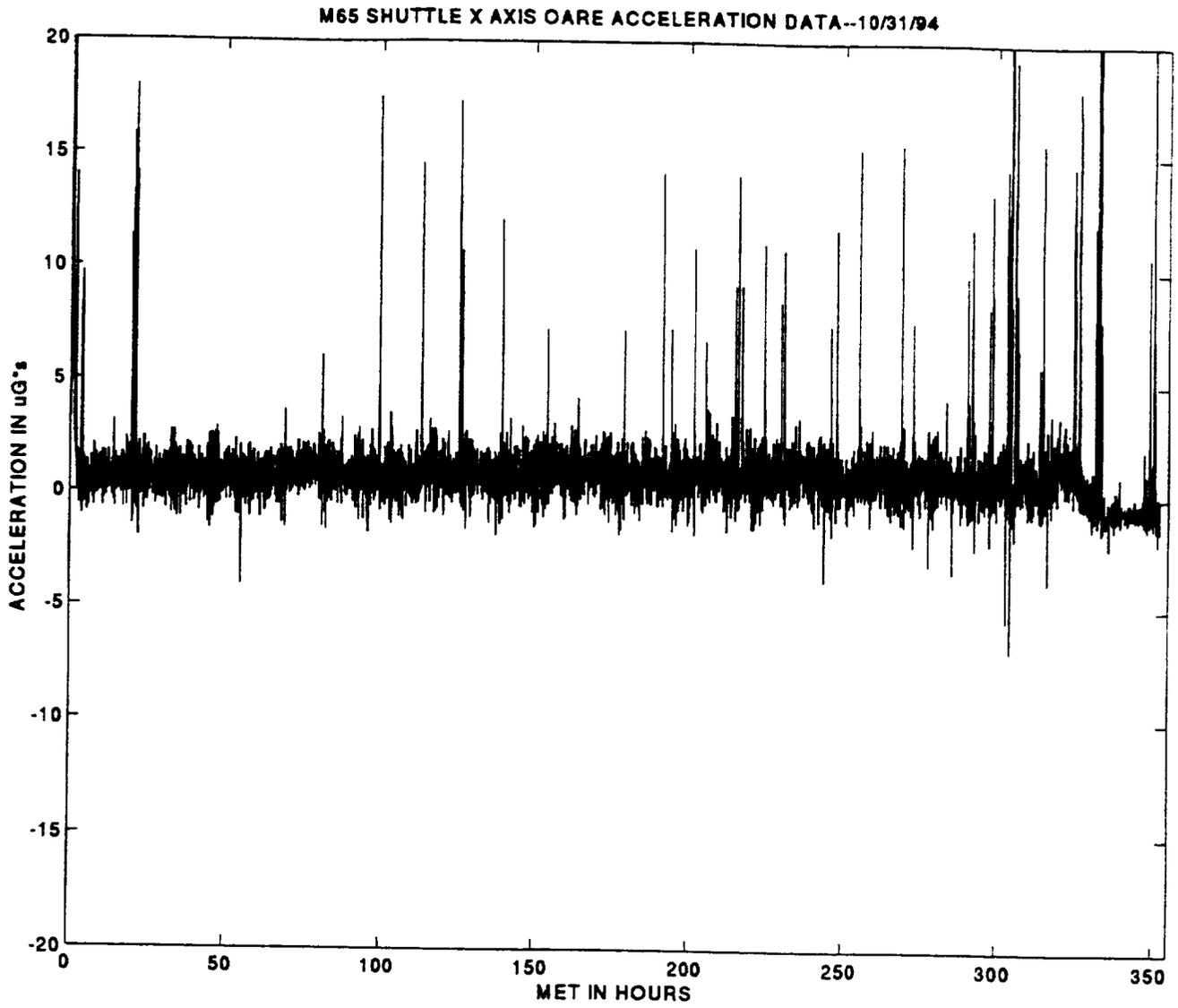


Figure 4. Shuttle X Axis STS 65 Acceleration History

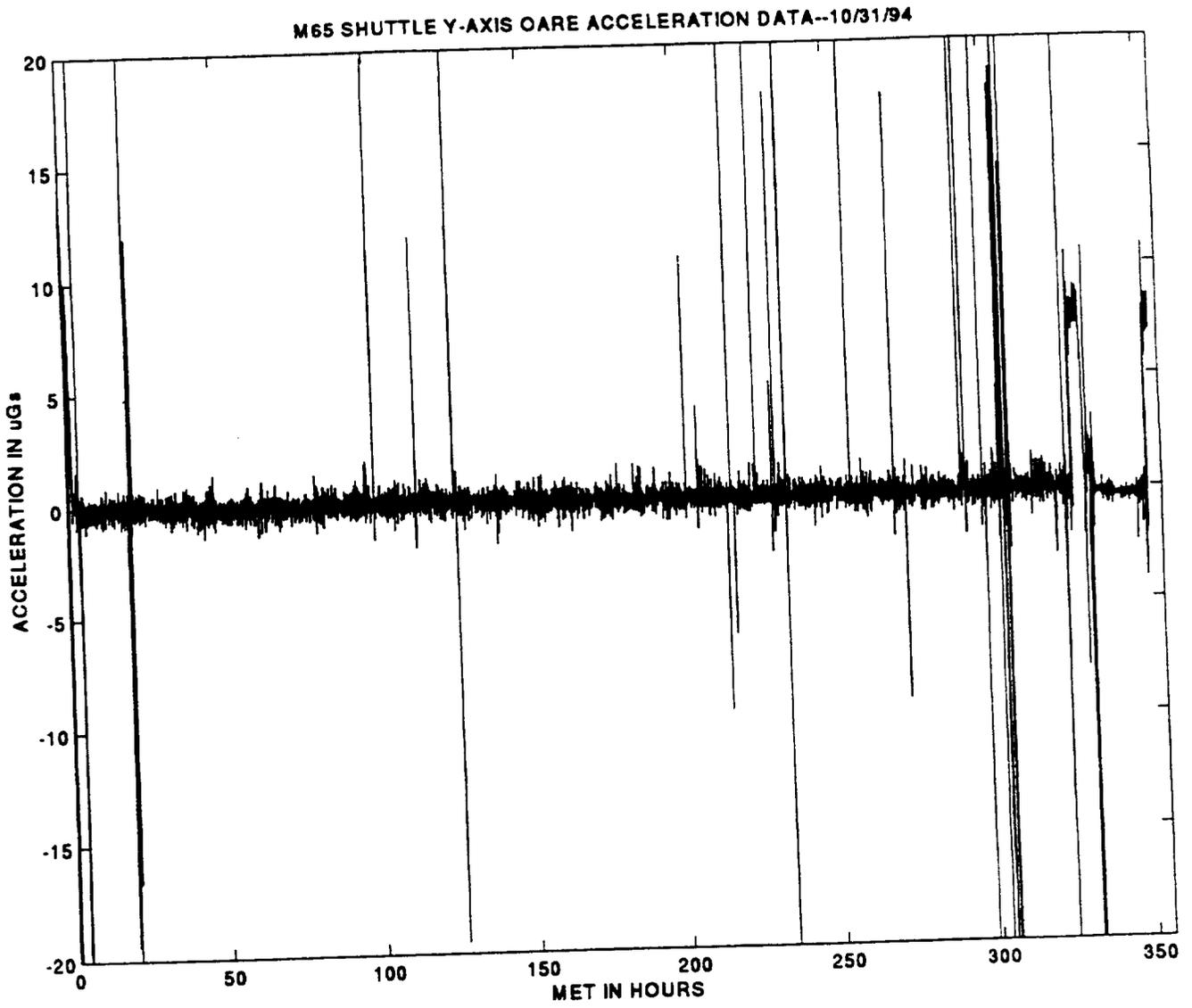


Figure 5. Shuttle Y Axis STS 65 Acceleration History

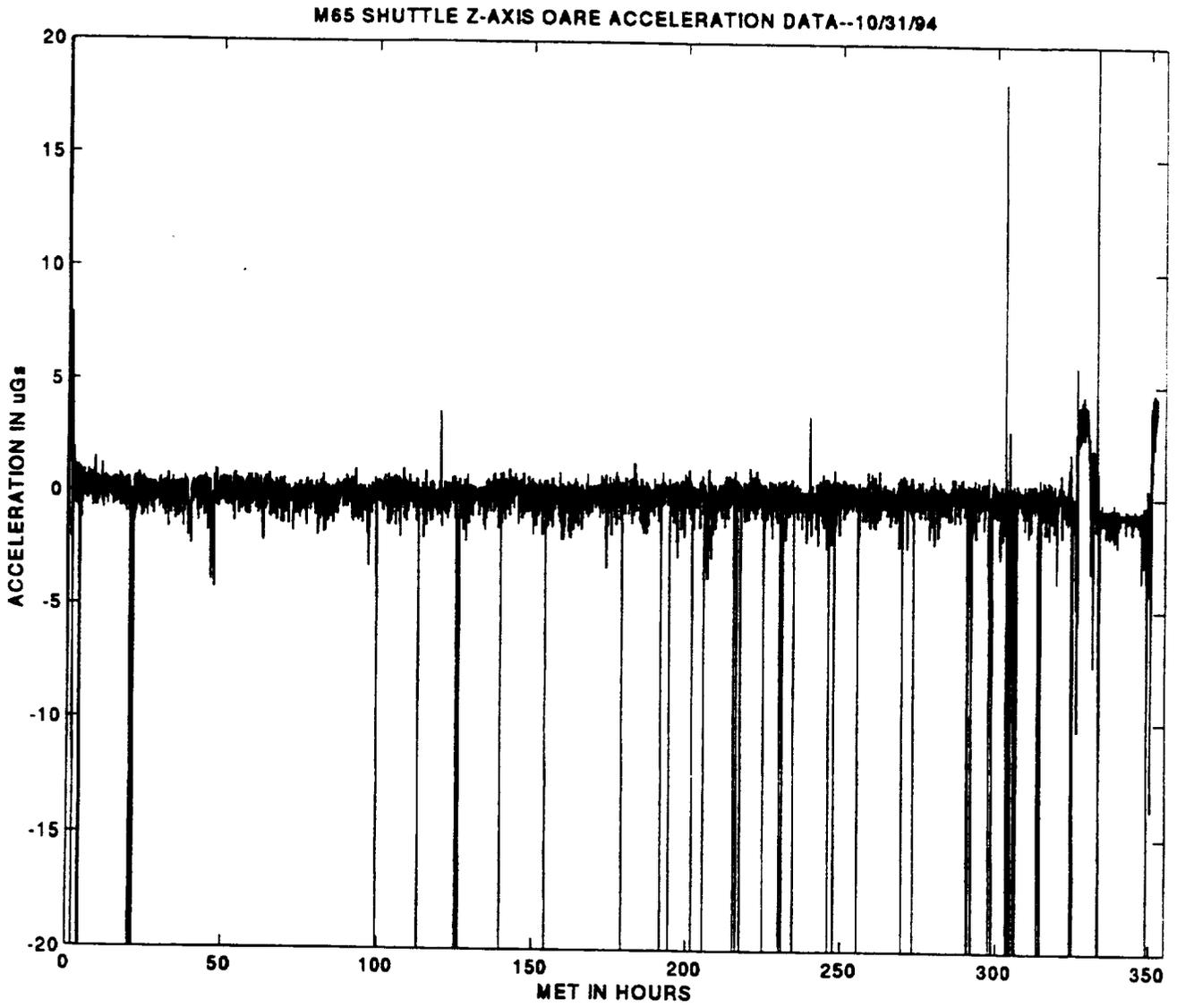


Figure 6. Shuttle Z Axis STS 65 Acceleration History

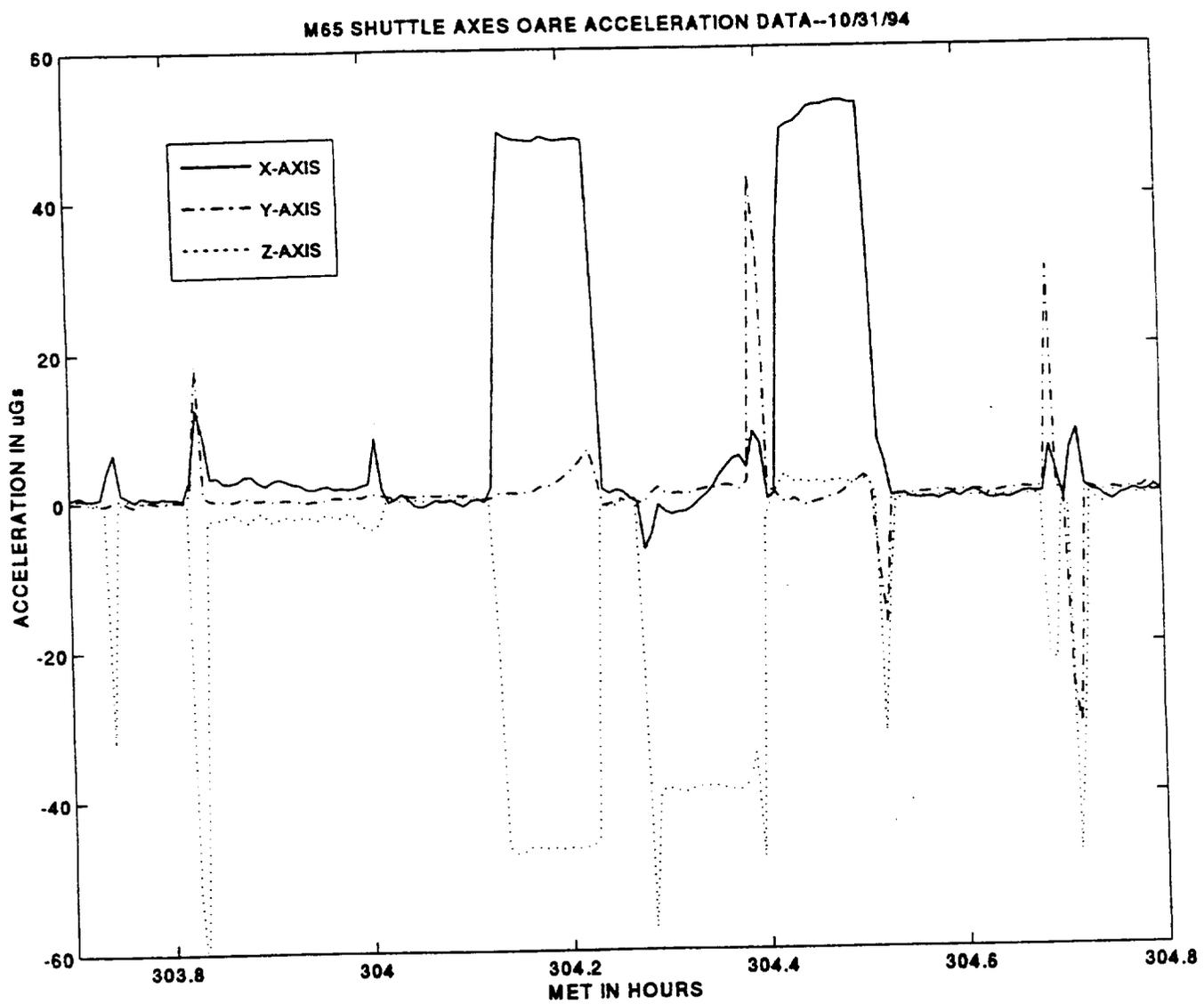


Figure 7. OARE Acceleration During Maneuvers

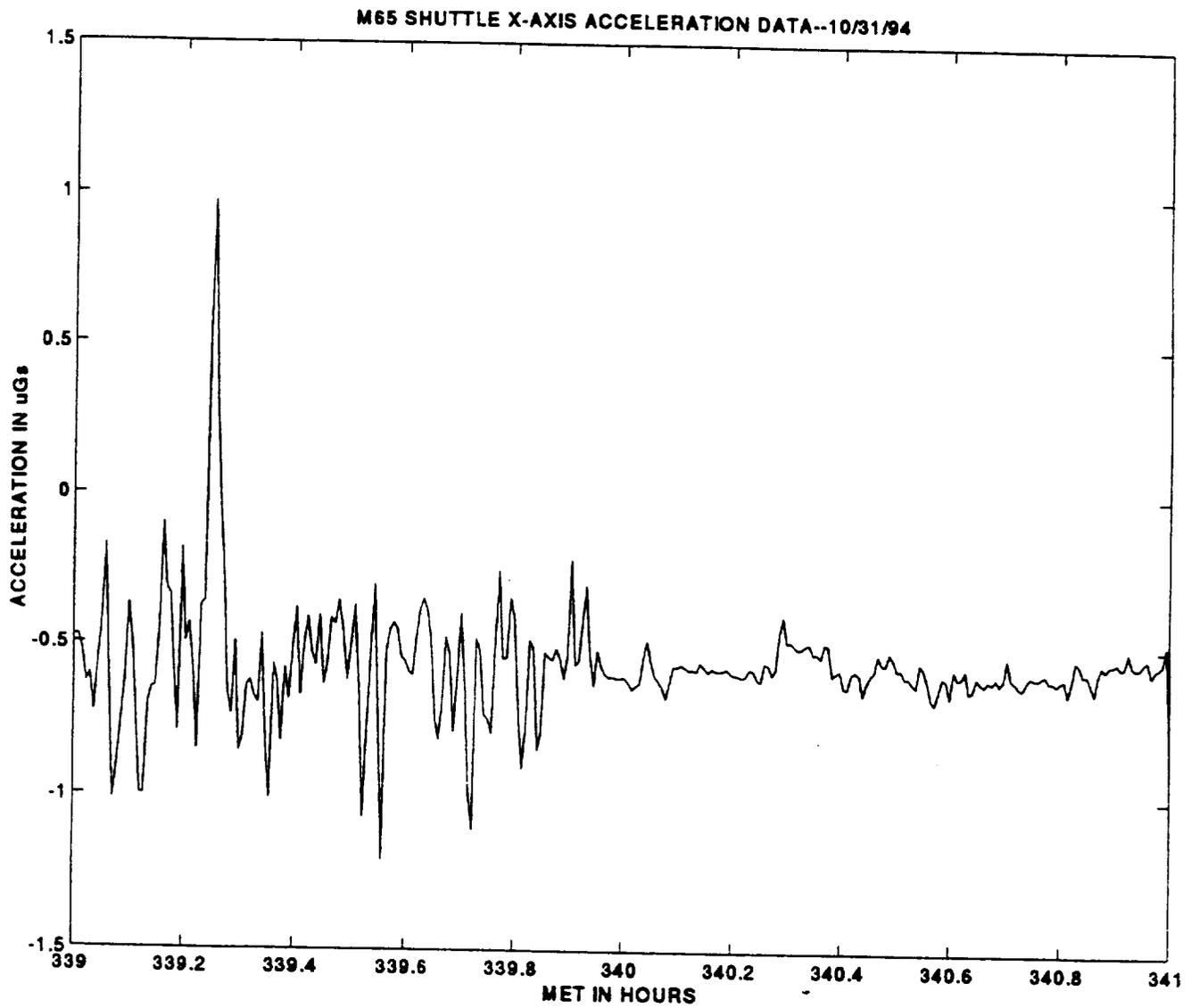


Figure 8. Shuttle X Axis STS 65 Acceleration Near the End of the Mission

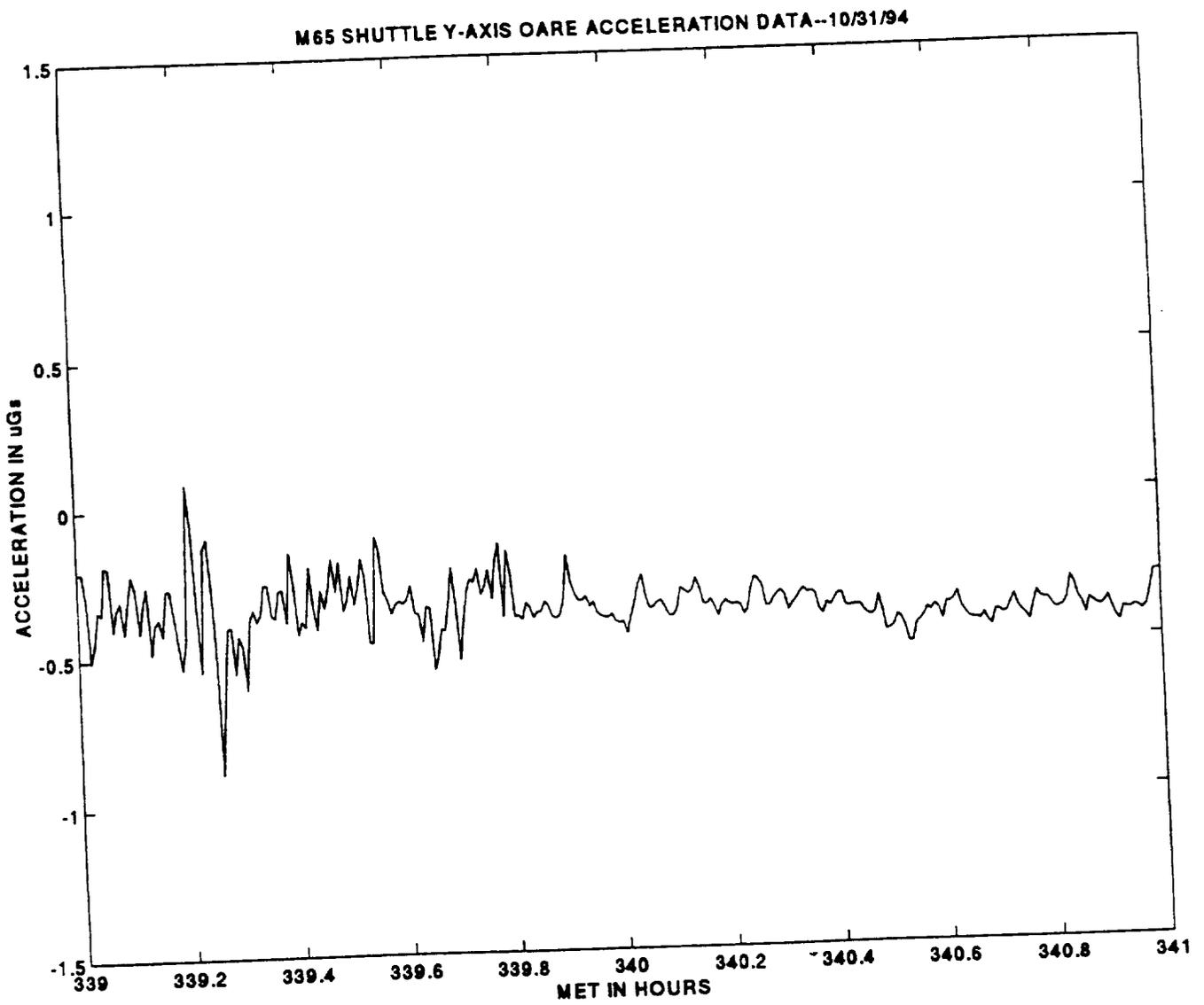


Figure 9. Shuttle Y Axis STS 65 Near the End of the Mission

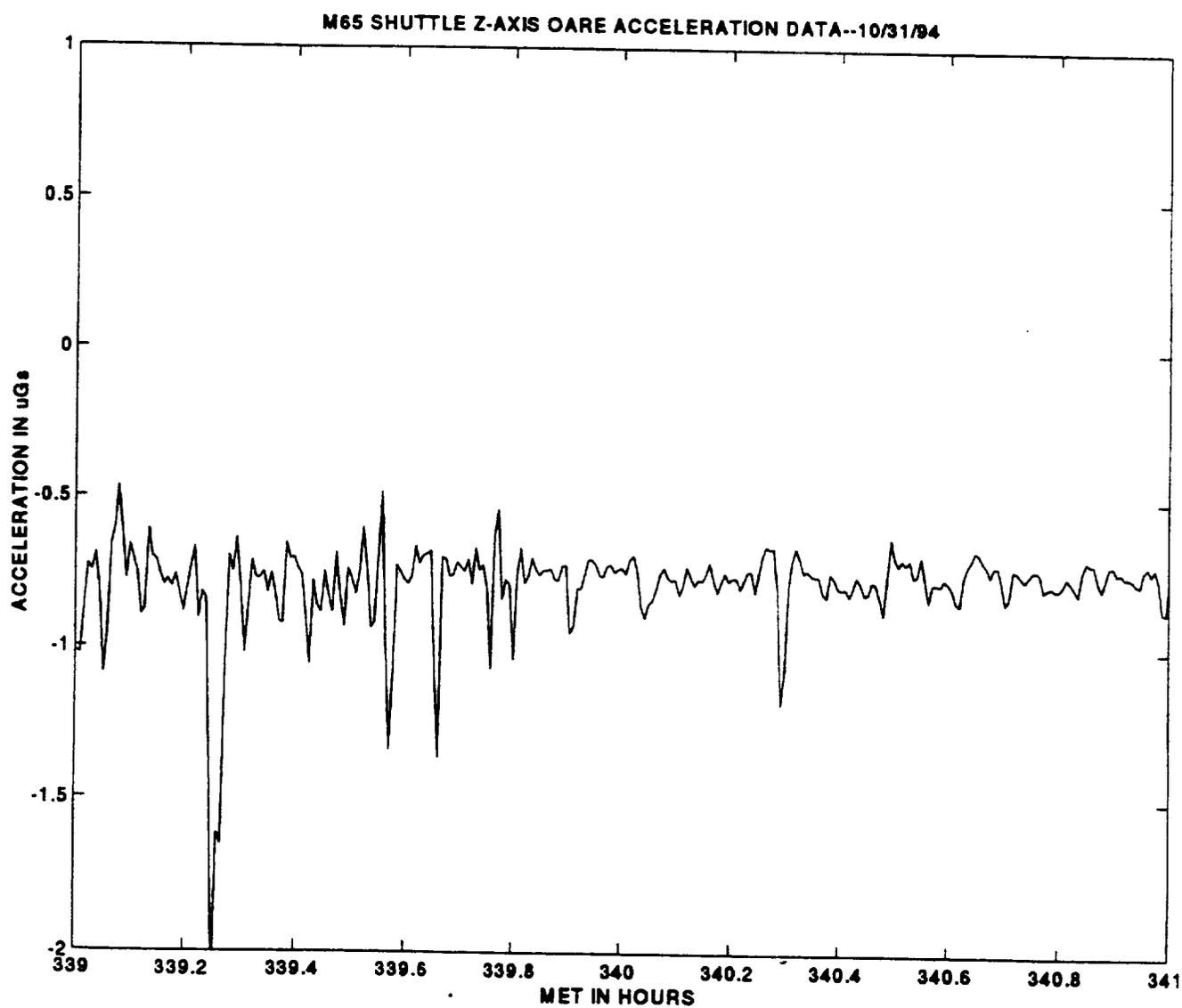


Figure 10. Shuttle Z Axis STS 65 Near the End of the Mission

2.4 STS 65 Anomalous Performance

On STS 65 there were some anomalies which were in general minor in nature. Many of these had been seen on previous missions and were not considered significant enough to fix at that time. The following is a discussion of these anomalies.

OARE Z Axis Scale Factor Anomaly

OARE's performance on STS 65 was similar to that on STS 62. The Z-axis C range scale factor calibration was still affected by jitter to a small degree. In addition, the OARE instrument in the C-range continued to show the characteristics of an "electronic bias shift" that was first noted in STS-58 [4]. The electronic bias shift manifested itself with small changes in the pre and post rate levels during the scale factor calibration on the Z axis in the C-range. This electronic bias shift was not apparent in the bias calibrations and appears to be an artifact that occurs only during the scale factor calibration period and, hence, does not affect the Z-axis data collection.

Ground and In-Flight Scale Factor Differences on Y and Z axes.

The scale factor calibration measurements measured in-flight using the rotary table assembly were nearly identical to those measured on STS-58 and STS-62 even though the temperature was considerably colder. However, these in-flight scale factors appeared to differ from the ground calibration factors by approximately 14% on the Y and Z axes and by about 3% on the X axis. This difference between in-flight measured scale factors and ground calibration factors is now being analyzed and has been shown to be a test effect related to additional cable capacitance in test cables used in the ground calibrations; i.e. when the erroneous ground test capacitance was removed, the ground measured scale factors match the flight scale factors to within about 2%. These scale factor analyses will be reported upon in a separate report.

Small Error in the On-board TrimMean Filter

In reviewing the processing algorithm for the bias calibration it was discovered that the flight software routine which does the trimmean calculation has a small error. It removes one more point on the high end of the distribution than on the low end of the distribution. This results in shifting the mean to a lower value than it should be. Estimated errors are 5.7 ± 0.3 counts on the X-axis, 1.6 ± 0.1 counts on the Y-axis, and 1.5 ± 0.1 count on the Z-axis. Since the flight software also processes the normal acceleration data by using the same algorithm, this error was self-correcting in the processing of the normal data from the EPROM shown in this report. However, these corrections should be applied to the bias functions shown in Table 2 for the C range when processing the raw telemetry data; i.e., the fitted constants A1 should be increased by 5.7 counts for the X-axis C range, by 1.6 for the Y-axis C range, and by 1.5 for the Z-axis C range.

Erroneous Reporting of Sensor Range following Scale Factor Abort

All Normal data files reported that each sensor channel was in range C following the second canceling of Reenter but data values indicated that all channels must have been in range A. This condition was not corrected until a condition occurred that caused automatic ranging; in this case, an external event that caused X axis saturation 2 hours later. The Normal data for this time period

was recovered by manual editing of the range codes in the ASCII formatted data files used for analysis. The correct range was then processed for the flight accelerations delivered.

The Status Log shows that this Reenter was canceled while Scale Factor was in the Rate step of Sequence #4. Normal ranging control is overridden by Scale Factor control during the Rate step. Range C was active for all sensor channels prior to start of Scale Factor and range A is commanded, by Scale Factor control, while the table is starting or stopping its Rate movement. It appears that the software action to abort Scale Factor activity at this critical time is inadequate. Although the general action of aborting a Scale Factor was previously tested, the abort probably was not stimulated in the narrow time window that would stimulate this defect.

Defective Scale Factor Data Record, with Loss of Scale Factor Data

Ground support software which reformats the SF_RAW data file for analysis declared a formatting error in the raw data file during processing of SF number 27, which is the one aborted when the first Reentry was canceled. [The processing software quits processing the raw data file when it encounters an error.] While this raw data file data formatting error has not been investigated in detail, it is suspected of being another deficiency associated with early termination of Scale Factor stimulated by the canceling of Reenter. We are optimistic that future corrective action for the Erroneous Reporting of Sensor Range problem will prevent future occurrences of this problem as well.

The effect of this defect is that Scale Factors during the last day of the mission have not been included in the correction of Normal data for this mission. This is not considered important for analysis in support of corrected Normal data measurements for the main portion of the mission. The raw data for the last Scale Factor of the mission exists in the Reenter data file and all Scale Factors are in the recorder output telemetry data. No plans presently exist to refine the ground processing software to recover M65 Scale Factor data following the point of defect or to investigate the exact nature of the raw data file defect.

3.0 OARE ACCURACY ANALYSIS

The OARE instrument provides high resolution measurements of sensor input axes accelerations, 3.05 nano-gs in the OARE X axis and 4.6 nano-gs for the Y and Z axes. The accuracy of these measurements is primarily determined by the degree to which the instrument can be calibrated over the time period of the measurements. Major sources of potential errors are the accuracies obtainable from the bias and scale factor calibrations.

3.1 Bias Errors

On STS 65, the bias was measured 84 times. From these measurements, the true bias was estimated by the fitting procedure discussed in section 2.3.1. Potential errors in these bias estimates arise from the statistical nature of the bias measurements as well as from potential systematic errors which have not been identified.

Random fluctuations in the recorded signal due to instrument noise or crew activity, etc., cause statistical errors in the individual bias measurements. In order to determine whether the differences between the bias estimates based upon fitted data and the actual measurements were consistent with the statistical errors that could be expected, a measure of the expected measurement errors was calculated. This measure consisted of the calculated average and the

RMS of the series of $(S(t+75)-S(t))/2$ for all times between mission elapsed times of 30 and 90 hours where $S(t)$ is the measured signal counts after the trimmean filter for a period of 500 samples (50 seconds). This corresponded to more than 8000 measured differences over a nominal period as can be seen in the acceleration plots. In this case, t is in seconds and 75 seconds is approximately the time between the bias measurements at the two table positions used to calculate the bias. The average of this series should be close to zero since there is no significant change in the average acceleration level over time. The RMS of this series is a measure of the expected measurement error in the bias measurements since the same signals, signal processing, and timing are used in the bias calculations. A comparison of the RMS of the signal differences and the RMS of the differences between the bias measurements and fit are shown in Table 4.

Table 4. Comparison of RMS of Signal Differences and RMS of Bias Fit Differences.

OARE AXIS AND RANGE	RMS of Signal Differences	RMS of Bias Fit Differences*	RMS of Fit in nano-gs*
X-C	94	138 (123)	421 (375)
Y-C	37	45 (29)	206 (133)
Z-C	29	26 (22)	119 (101)

*The number in parentheses is if the outlier points (from 1 to 3) are removed.

The magnitude of the RMS (standard deviation) of the signal differences and the bias fit differences are the same. The data are therefore consistent with the hypothesis that the differences between the bias fits and the bias measurements are due to the statistical noise associated with the bias measurements. This noise is primarily a result of crew activity and other exogenous events occurring when the bias measurements were made.

Additional support of this hypothesis can be found in the STS 62 data [3]. On STS 62 there were 71 total bias calibrations of which 27 occurred at relatively quiet periods. Biases were estimated on STS 62 in the same manner as on STS 65. Statistical measures of the bias fits on STS 62 are presented in Table 5. RMS values are presented for both all of the bias measurements and for only the 27 bias measurements made during the quiet periods. The same fit was used for the total data set.

Table 5. Statistical Measures of Bias Fits on STS 62 (71 total bias measurements, 27 Quiet)

OARE Axis and Range	RMS of Bias Fit Differences (All) (counts)	RMS of All Differences in nano-gs	RMS of Bias Fit Differences (Quiet) (counts)	RMS of Quiet Differences in nano-gs
X-C	60	185	19	60
Y-C	50	230	15	69
Z-C	30	138	15	69

As can be seen in Table 5, when the crew ceases activity during the quiet periods (on STS62 both crews had common sleep periods), the differences between the bias measurements and the estimated biases are considerably reduced. Again, this result is consistent with the hypothesis

that the differences between the bias fit and the measured values are due to noise induced by on-board shuttle activity.

Although the individual bias measurements differ significantly from the bias estimates, these differences are explained by the expected measurement error. Based upon statistics alone, we estimate that the error on our bias estimate is the RMS of the (bias measurements minus the bias estimate) divided by the square root of the number of degrees of freedom. There are 78 degrees of freedom on STS 65 bias fits and 21 on the quiet measurements on STS 62. Table 6 shows the resulting estimated statistical errors on the bias estimator.

Table 6. Estimated Statistical Bias Errors on STS 62 and STS 65

OARE Axis and Range	STS 65 Error (nano-g)	STS 62 Error (nano-g)
X-C	48	14
Y-C	24	15
Z-C	14	15

Non-random systematic errors are difficult to estimate, but are estimated to be about 20 nano-gs. The systematic errors and random errors should be added in quadrature to get the final estimate of the error on the bias. Thus, we expect bias errors of about 55 and 35 nano-gs for the X and Y/Z axes, respectively, on noisy missions such as STS 65. On STS 62 where there are quiet periods for calibrations, we expect bias errors to be on the order of 20-30 nano-gs.

This estimate of errors is consistent with the error estimate of 40 nano-gs provided by Blanchard et al. on page 18 of reference 4.

3.2 Scale Factor Errors

In the microgravity environment of the Orbiter, the quasi-steady acceleration measurements are typically on the order of 1 micro-g or less. Under these conditions, the bias errors are larger than the scale factor errors.

Measurements of the scale factors made during flight and those on the ground are now consistent to within 1-2 percent. We estimate the scale factor errors to be about 1-2 percent of the measured acceleration. These can be reduced with further study. At a 1 micro-g level, this corresponds to a 10-20 nano-g error. These should be added in quadrature with the bias errors.

3.3 Quasi-Steady Acceleration Measurements

As indicated, the primary OARE data recorded on the flight computer is processed through an adaptive trimmean filter. This trimmean filter provides a near optimum estimate of the mean of the quasi-steady acceleration population of measurements over the 50 second sampling period. This estimate is particularly beneficial in the calculation of the bias estimate and the estimate of orbital drag and gravity gradient effects. However, it tends to reject the effects of crew activity, thruster firings, and other exogenous events. Because many experimenters are interested in the true average of the acceleration measurements over the 50 second sample period, we are now considering incorporating the true average as well as the trimmean average for the sampling periods into the data recorded on the flight computer. In any case, the true

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13. ABSTRACT (Maximum 200 words) The report is organized into sections representing the phases of work performed in analyzing the STS 65 results and preparing the instrument for STS 73. Section 1 briefly outlines the OARE system features, coordinates, and measurement parameters. Section 2 describes the results from STS 65. The mission description, data calibration, and representative data obtained on STS 65 are presented. Also, the anomalous performance of OARE on STS 65 is discussed. Finally Section 3 presents a discussion of accuracy achieved and achievable with OARE.			
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average can be recovered from the telemetry data on STS 65 for those periods where it exists. For STS 73, the telemetry data will be available for all periods when OARE is operating.

4.0 References:

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